

## Anatomical adaptations of three species of Chinese xerophytes (Zygophyllaceae)

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**Abstract:** Secondary xylem characteristics and horizontal variations were described in three xerophytic species, *Zygophyllum xanthoxylon*, *Nitraria tangutorum*, *Tetraena mongolica* of Zygophyllaceae native to western China. All the species have obvious growth ring boundaries except sometimes discontinuous in *T. mongolica* and *Z. xanthoxylon* ring to semi-ring-porosity; simple perforation plate; alternate intervessel pitting; non-septate fibres; paratracheal confluent axial parenchyma; helical thickenings and heterocellular rays. However the vessel arrangement and quantitative features of vessels were different. Vessel elements tend to be shorter and narrower and more frequent in *T. mongolica* than in other two species that are hardly different could lead to greater conductive safety. The variation of vessel element length and fibre length along radial direction showed irregular tendency. There was significant difference in both fibre length and vessel element length among-tree and within-tree. Furthermore, the relationships between anatomical features and adaptability to desert environments were also discussed.

**Keywords:** Anatomical adaptations; Horizontal variations; Xerophytes; Zygophyllaceae,

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### Introduction

Zygophyllaceae consists of shrubs and herbs, very rare trees that have its main distribution in the eastern and the western hemispheres on arid lands, particularly on saline deserts. Most species of genera *Nitraria*, *Zygophyllum* and *Tetraena* are often found in northwest China.

*Nitraria* is typical plant in desert with strong ability to resist salinity and alkalinity, drought, wind and dust, and it can efficiently to fix moving sands, decrease wind speed. Furthermore, it is valuable for providing food, medicine and firewood. *Zygophyllum* is often planted as a fodder, medicine and important vegetation to control loss of water and erosion of soil. *Tetraena* is endangered shrubs due to its difficult natural regeneration and over-harvest as forage with higher combustibility. Particularly, they have strong ecological adaptability and amazing ability to fix moving sands and preserve soil and water in the arid and semi-arid regions of China.

Previous studies on wood anatomy of other species in Zygophyllaceae have mainly on general description (Schweingruber 1990). There is yet no detailed description of the wood of the selected species. The purpose of this paper is to provide preliminary information of the wood anatomy of selected species and discuss the relationship between anatomical characteristics of secondary xylem and adaptability to arid climate. The information obtained through this study will be useful for selecting and introducing suitable species to control desert expansion.

### Materials and methods

The study materials are *Zygophyllum xanthoxylon* (Bge.)

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Maxim, *Nitraria tangutorum* Bobr. and *Tetraena mongolica* Maxim. in Zygophyllaceae obtained from Wuhai City, China.

Five healthy trees of each species were felled and two discs (2–3 cm thick) from each sample tree were taken at the height of 20–30cm above the ground. All stem pieces measuring of these trees were roughly 0.5–2 cm in diameter. Some of the discs were immediately fixed in formalin-acetic-alcohol (5:5:90 v/v).

Wood samples were softened in ethylene diamine (Carlquist 1982a), subsequently sectioned with a sliding microtome moving on transverse, radial and tangential surfaces of the disks. Thin sections were stained with safranin, dehydrated in a graded alcohol series and mounted in Canada balsam for light microscope examination. Small blocks exposing transverse, radial and tangential surfaces were respectively prepared according to Exley *et al.* (1977) for scanning electron microscope (X-650, Hitachi Ltd Tokyo, Japan) observations. Maceration was prepared through soaking in Jeffrey's solution and mounted in glycerin-jelly. Quantitative data are based on 25 measurements of vessel element length and 50 of fibre length. Terminology and methodology follow the IAWA list of microscopic features for hardwood identification (IAWA Committee 1989).

### Results

#### General description of wood anatomy

Growth ring boundaries are generally distinct, sometimes discontinuous in *T. mongolica* and *Z. xanthoxylon*, marked by thick-walled latewood fibres or marginal parenchyma band; wood is somewhat ring to semi-ring porous; vessels arrange in tangential bands or slightly dendritic pattern in *N. tangutorum*; vessels are 31%–65% solitary, infrequently in tangential multiples of 2–3 or small clusters, but vessels present high grouping degree in *Z. xanthoxylon*; vessel frequency is 106–221·mm<sup>-2</sup>. Outline of vessels is round, oval or slightly irregular in cross section, with 31–49µm in tangential diameter; vessel element length is 93–150µm long (Fig. 1-6).

Rays are uniseriate in *T. mongolica*, occasionally biseriate,

2–5-seriate in other two species, infrequently uniseriate (Fig. 7–9); ray height varies from 88–981  $\mu\text{m}$  and frequency is 4–10/mm; body ray cells are procumbent in *T. mongolica* and *N. tangutorum*, square or upright, slightly procumbent in *Z. xanthoxylon* (Fig. 10–12). Pits are shown on the tangential wall and radial wall of ray cells, round, oval to elongate.

Intervessel pitting is alternate, some vested; pit apertures are round to oval, elongated, slit-like or partly coalescent, with 1.9–2.0  $\mu\text{m}$  in diameter (Fig. 13, 14).

Perforation plate is simple in oblique to almost horizontal end walls (Fig. 15).

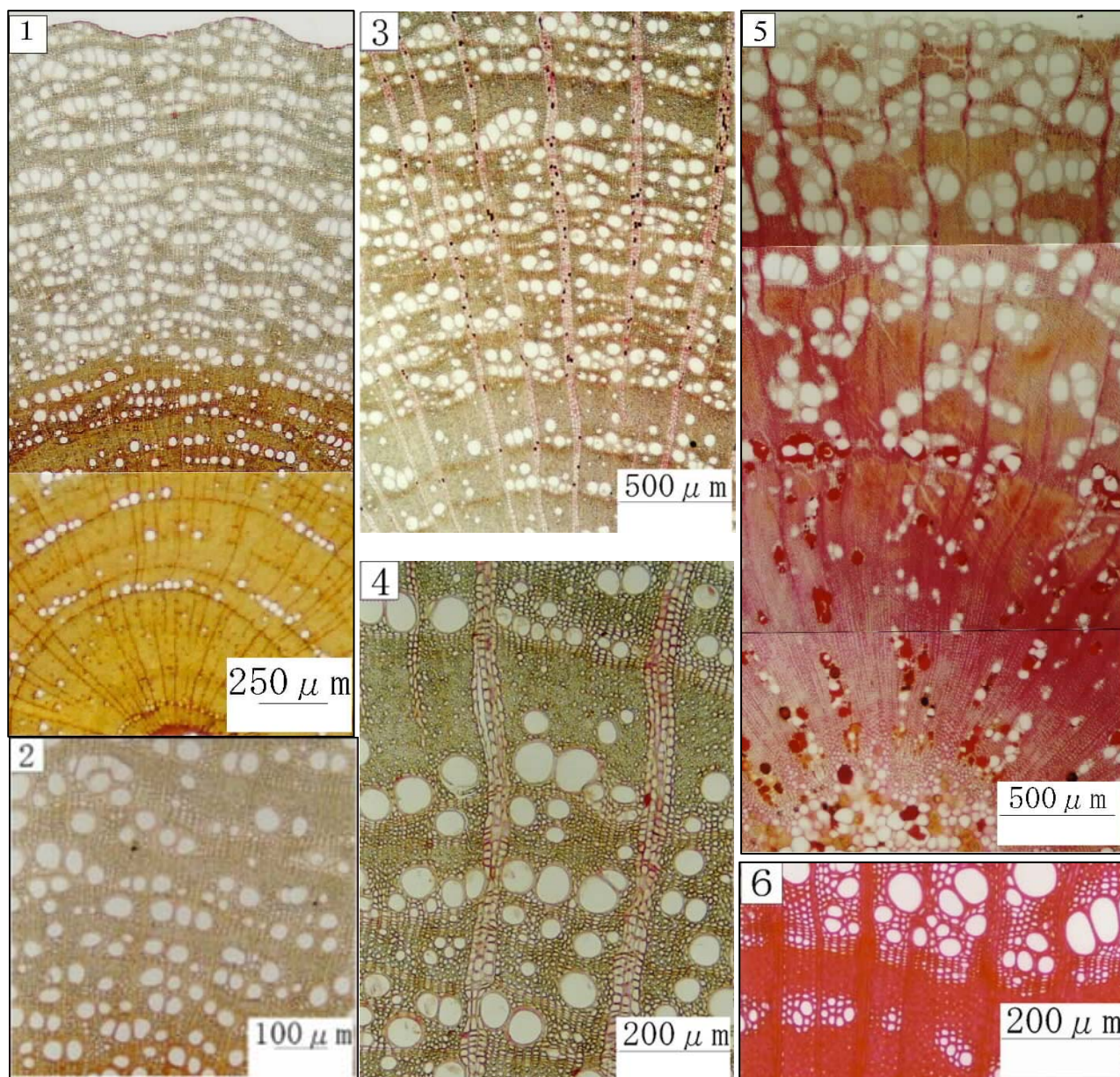
Vessel walls are smooth or with distinct helical thickenings

mainly throughout narrow vessels or confined to the tails of wide vessel elements (Fig. 15).

278–468  $\mu\text{m}$  long nonseptate fibres, mainly thick-walled, present with simple to minutely bordered; slit-like pits and bordered pits showed on fibre tracheid in *N. tangutorum* (Fig. 16).

Axial parenchyma abundantly present, paratracheal to scanty paratracheal or marginal bands, fusiform parenchyma cells present with 2–4 cells per parenchyma strand.

Gummy contents present in vessels in *N. tangutorum*, crystals present in ray cell in *N. tangutorum* (Fig. 17); rays, vessel element and axial parenchyma are storied and vessel wall surface is covered with warts in *N. tangutorum* (Fig. 18).

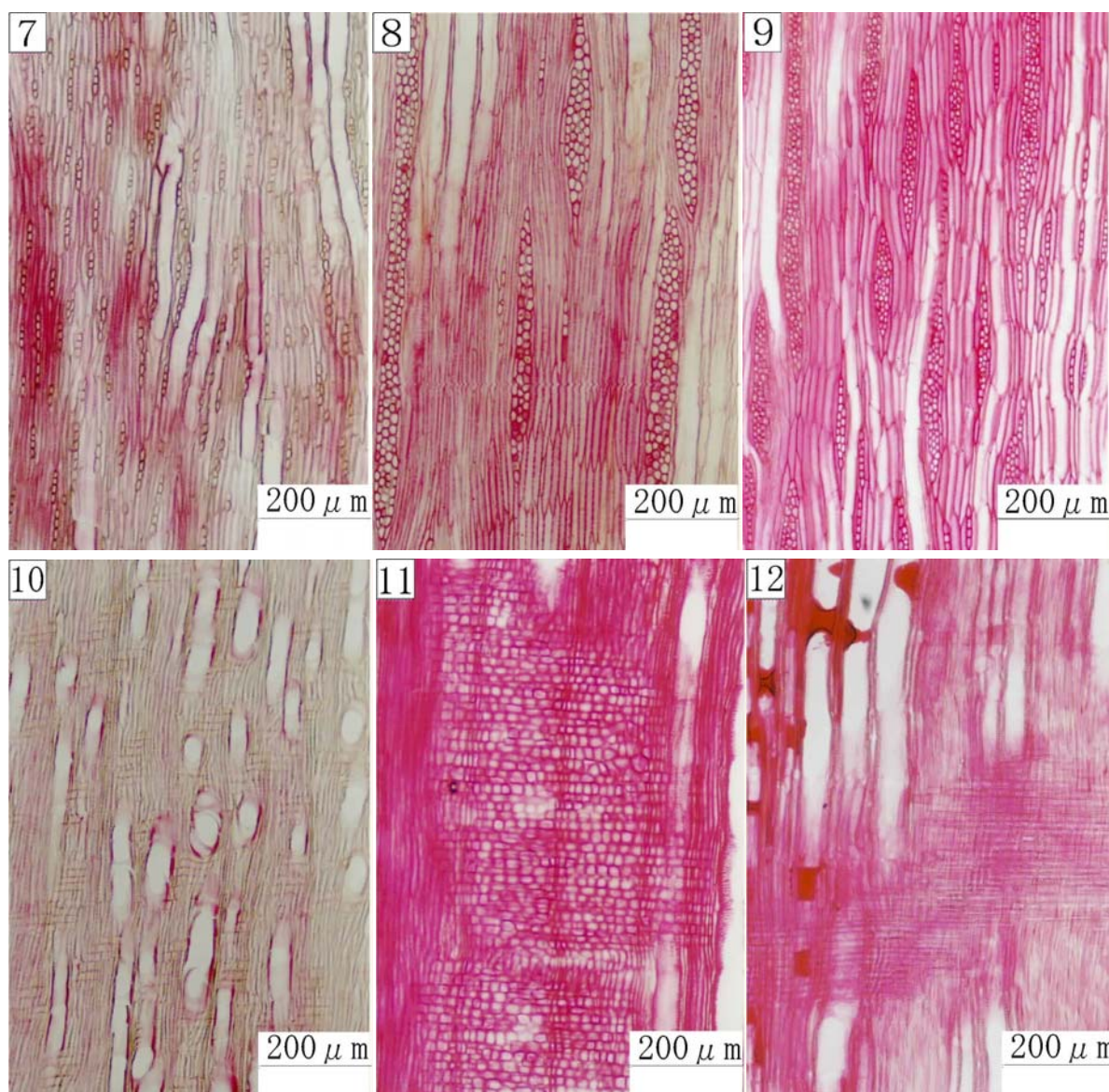


**Fig. 1–6 Light microscope photographs, Transverse section.**

Fig 1, 2 *Tetraena mongolica*. Fig.1 growth ring boundaries are distinct, occasionally continuous; Fig. 2 Vessels are solitary or in tangential multiples.

Fig. 3, 4 *Zygophyllum xanthoxylon*. Fig. 3. Wood is semi-ring porous with distant growth ring boundaries, occasionally continuous. Fig.4 Growth ring boundaries were marked by axial parenchyma bands.

Fig. 5, 6 *Nitraria tangutorum*. Fig. 5 Vessels are arranged in tangential to seemingly dendritic pattern. Fig. 6 axial parenchyma abundantly present, paratracheal or marginal bands.



**Fig. 7–12 Light microscope photographs,**

Fig. 7–9, tangential longitudinal section. Vessel elements, axial parenchyma, rays are storied to irregularly storied. Fig. 7 *Tetraena mongolica*, rays are uniseriate, occasionally biseriate. Fig. 8 *Zygophyllum xanthoxylon*, rays 2–5-seriate, infrequently uniseriate. Fig. 9 *Nitraria tangutorum*, 2–5-seriate rays. Fig. 10–12, radial longitudinal section. Fig. 10 *Tetraena mongolica*, Body rays were composed of procumbent cells. Fig. 11 *Zygophyllum xanthoxylon*, Heterocellular rays are composed of procumbent, square or upright cells mixed. Fig. 12 *Nitraria tangutorum*, ray cells composed of procumbent cells with marginal square cells.

### Ecological wood anatomy

From the quantitative features (Table 1) and from the horizontal variations according to their length (Fig. 19), it is clear that the vessel element length and tangential vessel diameter are very small in three species, less than 150 and 50 μm, respectively, in agreement with earlier observations in other xerophytes (IAWA Committee 1989). Among three species, *T. mongolica* has the larger vessel frequency, shorter and narrower vessel element than other two species, which improves safety for hydraulic conduction.

Vessel element length and fibre length were plotted from pith to bark on the basis of the measurement of samples taken at each ring. The results of horizontal variation with ring number were

shown in Fig. 19. Both the vessel element length and fibre length within one tree are more or less constant, and showed irregularly increasing or decreasing curves in *T. mongolica* and *Z. xanthoxylon*. While the length of the vessel element and fibre slightly decreased with the number of the ring from the pith in *N. tangutorum*.

Statistically, there was significant difference for fibre length and vessel element length among species and within species (Table 2). The longest and shortest average fibre lengths were 468 and 278 μm respectively. The longest fibres were observed in the species of *Z. xanthoxylon*, whereas the shortest fibres were found in the species of *T. mongolica*.

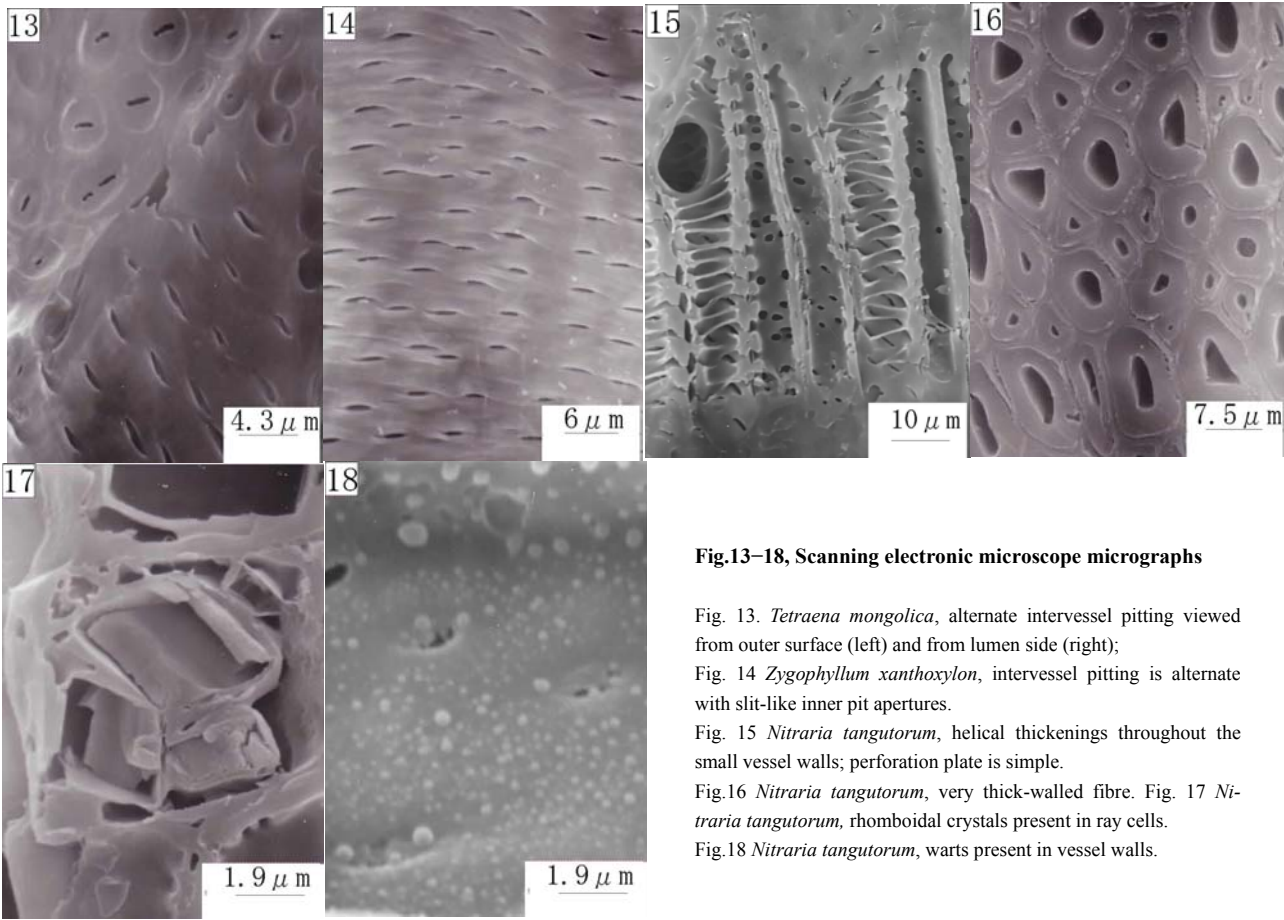


Fig.13–18, Scanning electron microscope micrographs

Fig. 13. *Tetraena mongolica*, alternate intervessel pitting viewed from outer surface (left) and from lumen side (right);  
Fig. 14 *Zygophyllum xanthoxylon*, intervessel pitting is alternate with slit-like inner pit apertures.  
Fig. 15 *Nitraria tangutorum*, helical thickenings throughout the small vessel walls; perforation plate is simple.  
Fig.16 *Nitraria tangutorum*, very thick-walled fibre. Fig. 17 *Nitraria tangutorum*, rhomboidal crystals present in ray cells.  
Fig.18 *Nitraria tangutorum*, warts present in vessel walls.

Table 1 Quantitative anatomical features of three species in Zygophyllaceae

Index	Nitraria tangutorum	Zygophyllum xanthoxylon	Tetraena mongolica
Vessel number per mm <sup>2</sup>	106(60-132)	110(80-172)	221(104-308)
Tangential vessel diameter (μm)	42(21-81)	49(18-86)	31(16-59)
Vessel element length (μm)	150(86-214)	138(61-226)	93(21-156)
Solitary vessels (%)	31(15-40)	65(43-82)	38(25-54)
Fiber length (μm)	404(250-578)	468(105-732)	278(82-417)
Vulnerability index	0.40	0.45	0.14
Mesomorphy index	59.4	61.5	13.0
Intervessel pit diameter (μm)	1.9(1.5-2.3)	2.0(1.4-2.9)	1.9(1.4-2.3)
Ray height (μm)	521(240-920)	981(340-3000)	88(40-210)
Number of rays per mm	8(7-9)	4(3-5)	10(7-14)

Table 2 Analysis of variance of fibre length and vessel element length of three species

	Vessel element length (F Value)	Fibre length (F Value)
Among species	197.92**	128.49**
Within species (age)		
<i>Nitraria tangutorum</i>	3.25**	34.06**
<i>Zygophyllum xanthoxylon</i>	2.09**	3.95**
<i>Tetraena mongolica</i>	2.74**	11.56**

\*\* Significant at 5% level; ns , not significant

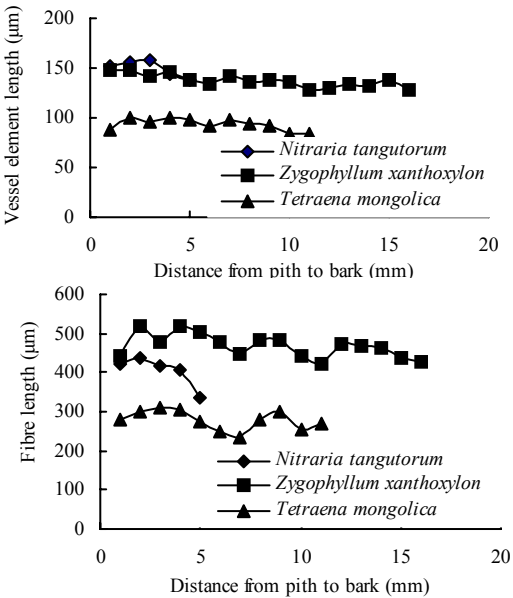


Fig. 19. Variations in vessel element length and fibre length of three species of Zygophyllaceae

Discussion

The secondary xylem of the three species can be distinguished by the qualitative and quantitative indices. These species grow in habitats subject to high water stress and the wood anatomical

features and leaf show adaptations correlated to environmental extremes. Leaf surface reduction with thick cuticles, photosynthesizing by green stems and cutinization of the outer walls in leaf epidermis enables plants to have the ability to withstand dry climatic periods (Villagra *et al.* 1997; Lindorf 1997). Wood or secondary xylem provides a complex tissue for water transport, mechanical strength, and for metabolic processes such as storage and mobilization of reserve carbohydrates and lipids (Baas 1986; Carlquist 1988; Zimmermann 1977, 1983). Ecological and evolutionary trends in vessel diameter, perforation plate type, vessel frequency, vessel member length, total vessel length, and fibre type have all been discussed in terms of their input to the safety and efficiency of water transport (Zimmermann *et al.* 1971 & Baas 1986). In general, the tendencies are for vessel members to become shorter and narrower as the aridity increases to prevent collapse of vessels under high negative pressures and vessels towards grouping in arid environments (Carlquist 1966, 1985; Baas *et al.* 1986; Zhong *et al.* 1992; Fahn *et al.* 1986 & Lindorf 1994). Vessels mainly solitary or few vessel grouping, narrow and numerous could lead to greater conductive safety because it renders the inactivation of any vessel less harmful by enabling the water transport to be transferred to an adjacent vessel (Carlquist 1984). This tendency agreed with general xeric character that was observed in other families (Baas 1988, Carlquist 1984, 1988). Vessel elements tend to be shorter and narrower and more frequent in *T. mongolica* than in other two species (Table 1 and Fig. 19). It indicates *T. mongolica* is more xeric.

Vulnerability (mean vessel diameter divided by the mean number of vessels per sq. mm) and mesomorphy (vulnerability multiplied by mean vessel element length) are proposed by Carlquist (1977, 1992) to express the conductive safety and efficiency within xylem part. Larger indices ( $V > 1$ ,  $M > 800$ ) indicate more mesomorphic. Table 1 shows that *T. mongolica* is more xeromorphic than other two species. Both efficiency or maximal conductivity and safety are strongly related to vessel diameter and vessel frequency. Increased vessel diameter increases efficiency of water conduction dramatically, but at the same time it decreases safety. However, ring-porosity and presence of different vessel size classes in general are of importance for the combined efficiency and safety of xylem sap transport at different times in or throughout the growing seasons (Baas *et al.* 1987). The gradually decreased vessel diameter from earlywood to latewood allows for optimal transport efficiency by wide vessels and provides great conductive safety through the narrow latewood vessels (Zimmermann 1982; Baas *et al.* 1988 & Woodcock 1994).

Apart from these quantitative characters, the qualitative characters show ecological correlations. The growth ring boundaries in *T. mongolica* and *Z. xanthoxylum* are discontinuous maybe due to the irregular change of seasonal climate. Some narrow vessels in three species have coarse helical thickenings, which increases cell wall strength to withstand high pressures or enlarges wall surface to promote water bonding to the surface (Carlquist 1975, 1982). In this study, all species show helical thickenings, together with vessel groups and tracheids, which are associated with greater conductive safety in arid environments.

Carlquist and Hoekman (1985) point out there are many other alternative strategies for a plant to survive in water deficit conditions except wood features. Wood structure should be considered as one of the xeromorphic characteristics.

The difference in range of fibre length is attribute to differences in age of wood and to the diverse environmental conditions

in this study area. The wood fibres are thick-walled and have narrow lumina with varied shape and size. Some of them are straight and spindle-shaped while others have undulated walls. Their length including sharp points shows significant variation. From this study, vessel element length and fibre length are short due to its short fusiform initials, in agreement with the results from Carlquist (1988).

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